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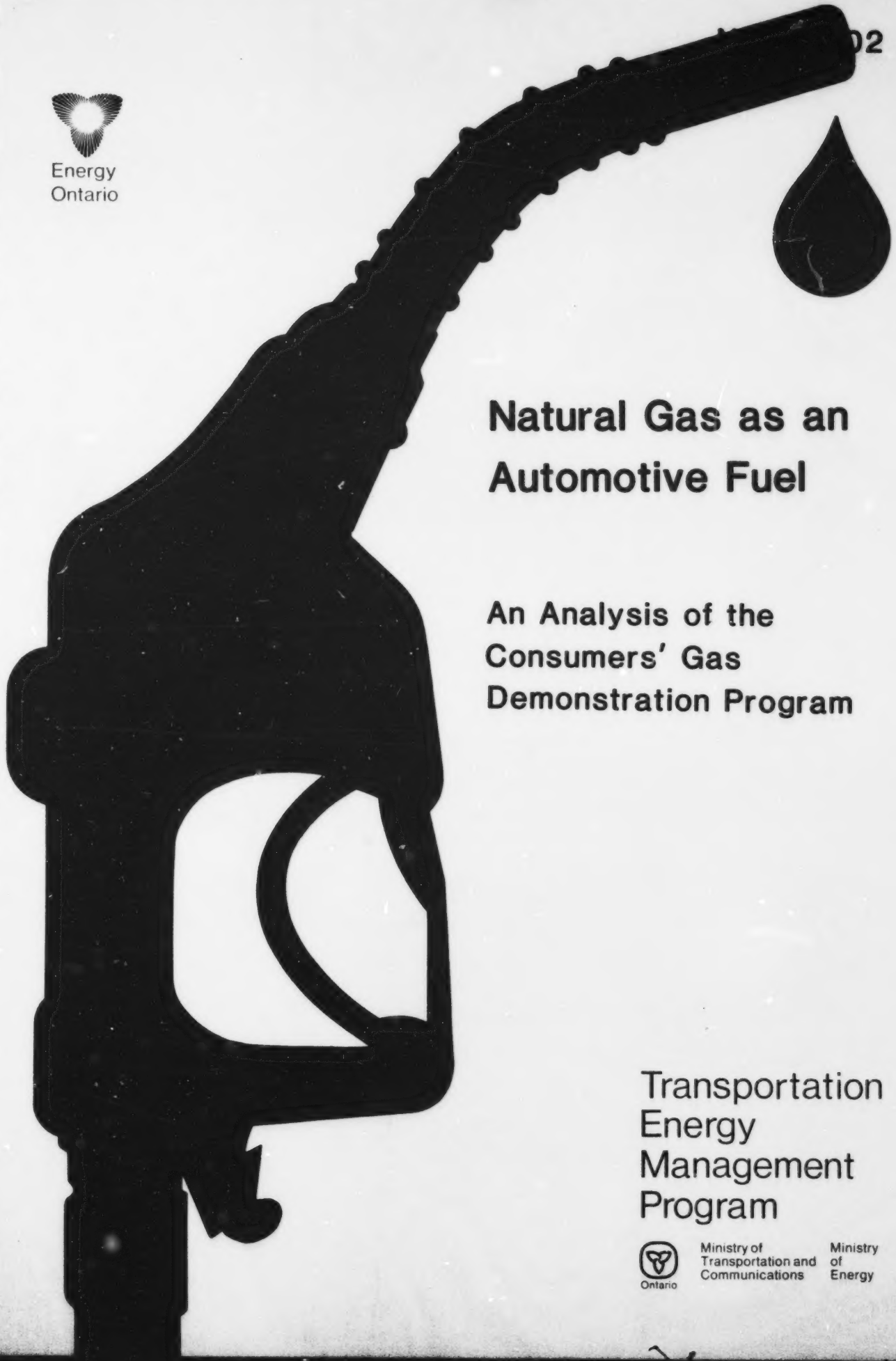

Natural Gas as an Automotive Fuel

An Analysis of the Consumers' Gas Demonstration Program

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An Analysis of the Consumers' Gas Demonstration Program

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Abstract:
The Technology and economics of natural gas as a vehicle fuel in Ontario were successfully demonstrated by the Consumers' Gas Co. Ltd. in a program jointly funded by industry and government. A slow/fast-fill compressed natural gas (CNG) fuelling station with a nominal capacity of 110 m^3/h (65 scfm) was built and 22 service vans were converted to operate on a CNG/gasoline dual-fuel mode. The operation of the station and the fleet was carefully assessed and reported on over a one-year period by Consumers' Gas. The project monitoring and support functions were carried out by the Ministry of Transportation and Communications. This report was prepared by MTC to summarize and interpret the technical and economic information generated in this project.

Key Words: Natural Gas, gasoline, alternative automotive fuel, Consumers' Gas demonstration program

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EXECUTIVE SUMMARY

The technology and economics of natural gas fuel in Ontario were successfully demonstrated by the Consumers' Gas Co. Ltd. in a program jointly funded by Consumers' Gas, Ontario Ministry of Energy, and Energy, Mines and Resources Canada. A slow/fast-fill compressed natural gas (CNG) fuelling station with a nominal capacity of 110 m^3/h (65 scfm) was built and 22 service vans were converted to operate on a CNG/gasoline dual-fuel mode. The operation of the station and the fleet was carefully assessed and reported on by Consumers' Gas over a one-year period. The project monitoring and support functions were carried out by the Ministry of Transportation and Communications. The present report has been prepared by MTC to summarize and interpret the technical and economic information generated in this project.

One of the purposes of the demonstration was to obtain and disseminate information regarding natural gas as a vehicle fuel. The fuel efficiency of the fleet, the operation of the station and the fleet along with the economics of natural gas utilization were the specific areas in which data were obtained.

The program demonstrated that, with the presently available equipment, natural gas can be beneficially used as a vehicle fuel in Ontario. However, improvements are needed in a number of areas in order to enhance market acceptability and energy utilization efficiency. The main conclusions of this work, including the problems identified, are presented below:

1/ In a service fleet operation involving urban driving conditions and prolonged idling periods, fuelling of spark-ignition engines with either natural gas or gasoline results in comparable energy utilization efficiencies. Consumers' Gas predicts a 9% efficiency advantage for CNG; however, statistical analysis of the fleet data indicates a rather low confidence level for this prediction. Thus, until a more reliable data base is established the road fuel consumption equivalence of the two fuels has to be based on their energy contents; i.e.,

1 L of gasoline can be typically substituted by 0.96 m^3 of natural gas.

2/ Large variations in relative fuel efficiency with natural gas and gasoline may arise from differences in the pre-conversion state of the vehicles and the conversion process. This observation was made during the MTC chassis dynamometer evaluation of two Consumers' Gas dual-fuel vehicles. Reduction of such variations requires that prior to conversion each vehicle is set to manufacturers' specifications and that during conversion the ignition and carburation systems of each vehicle are adjusted to minimize CNG consumption while retaining adequate performance.

3/ The average CNG consumption of the demonstration fleet was 27.2 m^3/100 km. The month-to-month variation of the fleet fuel consumption was relatively large, with the 90% confidence interval for the average monthly fleet fuel consumption being 2.6 m^3/100 km wide. However, this variation correlates very well with ambient temperature and constitutes a systematic variation. For instance, CNG consumption in the coldest three months of 1981/82 was found to be approximately 30% higher than that in the warmest three months. The vehicle-to-vehicle variation in CNG consumption which constitutes a random variation is less pronounced, viz., the 90% confidence interval for the average annual vehicle fuel consumption is 0.8 m^3/100 km wide. Thus, the Consumers' Gas demonstration has succeeded in producing consistent CNG consumption data.

4/ The use of natural gas appears to provide the potential of doubling engine oil life. This preliminary finding is going to be substantiated by Consumers' Gas as part of their on-going development program.

5/ A number of deficiencies were discovered in the CNG demonstration vehicles. These included frequent failure of the vehicle mounted fuel check-valves, poor cold-weather startability, rough engine idling and 20% reduction of acceleration performance. These deficiencies can be eliminated by research and development aimed at improving conversion equipment and designing optimized natural gas engines.

6/ The fuelling station dispensed 68 000 m^3 of natural gas during the demonstration period. In this process 11 094 kWh of electricity were consumed. Thus, the average compression energy consumption amounted to approximately 16 kWh/100 m^3.

7/ The operation of the fuelling station ran smoothly. However, a number of failures related to seals, regulators, valves and switches were encountered which caused temporary shutdown of the system. Consumers' Gas will continue to monitor the performance of the fuelling station components in an effort to overcome difficulties that relate specifically to the use of natural gas.

8/ Measurement of the exhaust emission levels of two of the fleet vehicles at MTC indicate that the CNG conversion equipment and procedures may strongly alter the level of pollutant emissions. Contrary to common belief, a poor CNG conversion may result in more pollution.

9/ The cost-benefit data accumulated during the demonstration indicate that under the present pricing structure and with the existing government grants and tax incentives, use of natural gas as a vehicle fuel is very economical in Ontario. Operators who choose to purchase natural gas from public retail stations can expect to pay for the conversion costs in 0.5-3 years depending on whether a factory-conversion or a retrofit is involved and depending on the annual CNG consumption. On the other hand, for those who choose to operate their own fuelling station and a CNG vehicle fleet, the payback period for the station and the conversion of the vehicles is expected to be 2-4.2 years provided that at least 50% of the station capacity is utilized on an annual basis.

1/ INTRODUCTION

The use of natural gas as a vehicle fuel is being strongly encouraged in Canada. Provincial Governments and the Federal Government introduced tax incentives and grants making natural gas reasonably competitive with gasoline and diesel fuel.

However, lack of experience with natural gas handling equipment and the large initial costs involved remain as major impediments to fleet conversions. Consequently, the Ontario Provincial Government and the Canadian Federal Government have found it necessary to provide additional support to industry in rder to encourage the development and dissemination of essential expertise. In this report, the major results produced in the first one of these de onstrations, e.g., the Consumers' Gas demonstration, is summarized and interpreted.

The Consumers' Gas demonstration involved construction of a fuelling station, conversion of 22 vans to the CNG/gasoline (compressed natural gas/gasoline) dual-fuel mode and monitoring of the vehicle fleet and the fuel station to gain experience with natural gas usage. The fuelling station was installed at the base of the Consumers' Gas fleet operations near downtown Toronto at 405 Eastern Avenue. Vehicle conversions were carried out by Consumers' Gas staff using Diversified Fuel Systems Co. equipment. These two phases of the program were completed in August 1981.

The fleet monitoring phase of the program was conducted over the period of October 1, 1981 to September 30, 1982.

Consumers' Gas documented their experience in this program with three progress reports [1, 2, 3] and a final report [4], which will be republished by the Canada/Ontario Conservation and Renewable Energy Demonstration Program. In addition, a separate report [5] was submitted on the details of the vehicle conversion and the refuelling station designs. MTC staff analysed the fleet data submitted by Consumers' Gas and commented on the progress of the program. In addition, two of the demonstration vehicles were tested on the MTC chassis dynamometer to determine the effect of the conversions on vehicle energy consumption, exhaust emissions and performance in a controlled environment.

In this report, the main results of the demonstration program in fuelling station performance, vehicle fleet performance and overall economics are summarized.

Most of the results presented here were generated by an independent analysis of the fleet data.

2/ DESCRIPTION OF THE FUELLING STATION AND VEHICLE CONVERSIONS

2.1/ Fuelling Station

The Consumers' Gas CNG fuelling station was opened in September 1981 as the first of its kind in Ontario. It was built at the Station 'B' depot of Consumers' Gas on 405 Eastern Avenue in downtown Toronto. The design and construction of the facility were done by Consumers' Gas personnel.

The fuelling station incorporates a compressor, a slow-fill refuelling header and a quick-fill cascade system. The compressor and the quick-fill system are located at the centre of the property -- at least 46 m away from the property line on each side and sufficiently remote from vehicle and pedestrian traffic.

The compressor is a two-stage, water-cooled Norwalk unit which is driven by a 18.64 kW (25 hp) electric motor. At the 1.2 MPa (175 psi) inlet pressure available at the site, it provides 110 m^3/h (3885 scfh) of natural gas at a fill pressure of up to 25 MPa (3600 psi). It is housed in a steel prefabricated building and is mounted on a concrete slab. The building is vented on all sides and through the roof which allows adequate natural ventilation to prevent natural gas buildup. The compressor itself has elaborate safety features which allow shutdown at high temperature, low oil pressure and high or low suction pressure conditions as well as safe venting provisions. In addition, the service line to the compressor incorporates a number of valves, a regulator and a meter to ensure safe and reliable operation of the facility.

The fuelling of the vehicles is normally done using the slow-fill approach. The slow-fill header (located at 0.61 m below grade) serves seven risers each of which supply four refuelling hoses. Thus, 28 vehicles can be fuelled simultaneously. The service pressure on the slow-fill components never exceeds 20 MPa. The refuelling connections are steel quick-disconnect type couplings with self-sealing poppet valves which prevent gas flow unless the couplings are completely connected. The fuelling system incorporates extensive safety devices including shut-off and vent valves.

The quickfill facility allows fuel dispensing within 3-4 min. It incorporates a fully automated storage cascade with 20 cylinders rated at 25 MPa (3600 psi) service. At this pressure the cascade contains approximately 283 m^3 of natural gas. Each tank in the cascade storage system is protected against overpressurization by a burst disc set at 34.475 MPa (5000 psi)

During the demonstration period, the fuelling station serviced 22 Consumers' Gas vans and a few customer vehicles. However, the capacity of the compression equipment allows servicing of up to 50 vehicles.

The total acquisition cost of the fuelling station is estimated by Consumers' Gas to be $180 000 (1981 Canadian dollars).

2.2/ Vehicle Conversions

In August 1981, 22 Consumers' Gas vehicles were converted to operate on a dual-fuel CNG/gasoline mode. These were eight Ford Econoline and 14 Chevrolet Van Dura gas fitters' vans all stationed at the Eastern Avenue depot.

The conversion kits were supplied by the Alternative Fuel Systems Co. (now, Diversified Fuel Systems Co.) of Windsor, Ontario. The main elements of this ULC approved system are the Tartarini pressure regulator and air-fuel mixer. The regulator is a three-stage unit with a built-in electric fuelock, a primer, a power valve, and a pressure gauge. In addition, it includes a water jacket through which the engine coolant is circulated to prevent hydrate formation. The first stage of the regulator reduces the gas pressure to 245 kPa (35 psi) and the second stage to 101 kPa (14.7 psi). The mixer vacuum is applied to the third stage in order to pull the gas through the carburettor.

The first stage of the regulator incorporates a safety valve designed to close in the event of diaphragm rupture. Furthermore, the fuelock includes a vacuum switch which senses the loss of engine vacuum and closes the main CNG solenoid at the inlet to the first stage.

The primer solenoid allows fuel flow between the first and last stages. The power valve, on the other hand, allows supplementary fuel flow between the second and third stages of the regulator in response to wide-open-throttle demand.

The air-fuel mixer used in this system is mounted over the carburettor and at the centre of the air filter. it contains a venturi ring with numerous holes in its periphery and a movable plate placed over it. Natural gas is dispensed through the venturi ring holes. The diameter of these holes and the distance between the plate and ring are matched to the engine displacement. In the gasoline mode, an electrically activated vacuum solenoid lifts the venturi plate and thus stops natural gas flow.

The fuel storage system on each vehicle consists of two Taylor-Wharton high pressure cylinders which are DOT 3AA rated for 24.8 MPa (3500 psi) service. Each cylinder has a water capacity of approximately 44 L and a mass of 65 kg. The combined fuel capacity of the two cylinders is about 23 m^3 at 20.7 MPa (3000 psi) working pressure and 21°C. Range tests conducted by Consumers' Gas indicate that this capacity provides a vehicle range of 90-115 km.

In each vehicle, the gas cylinders are mounted vertically behind the driver's seat in an inverted position with the shut-off valve protruding through the vehicle floor. Hence, potential leak sites are excluded from the vehicle interior. In addition, each cylinder is equipped with a fusible burst disc set to relieve at 34.5 MPa (5000 psi) pressure and 100°C (212°F).

The high pressure delivery lines are of seamless stainless steel with a 9.5 mm outside diameter and a 1.25 mm minimum wall thickness.

In addition to the carburation system, the ignition system of the vehicles is modified, viz., spark-timing is advanced by 7-13° in order to mitigate the effects of slower flame speed in natural gas/air mixtures [6]. Operation on gasoline and natural gas at the same fixed timing schedule results in sub-optimal fuel efficiency with one or both fuels. The use of dual ignition curve spark advance modules offers a solution to

this problem. However, this option was not incorporated into the Consumers' Gas demonstration vehicles.

All conversions were done by Consumers' Gas personnel following a training workshop of the conversion kit supplier. Upon completion of the conversion process, each vehicle was pressure tested with nitrogen at 27 MPa. Subsequent to this test, the vehicles were given a final adjustment on natural gas by utilizing a chassis dynamometer.

The average cost of the conversion, including labour and material, is estimated by Consumers' Gas to be $1800 (1981 Canadian dollars).

3/ RESULTS OF THE DEMONSTRATION PROGRAM

3.1/ Fuelling Station Performance

During the one-year demonstration period, the fuelling station dispensed 68 000 m^3 of natural gas at a wholesale cost of $8536.68. This required consumption of 11 094 kWh of electricity costing $688.95. Thus, the total CNG fuel cost was $9225.63. Almost 90% of the natural gas was consumed by the 22 Consumers' Gas vans.

The monthly throughput of natural gas at the refuelling station ranged between 3313 m^3 and 7079 m^3; the lower amount being representative of summer months while the higher of the winter months. On the average, the compressor operated for only 2.3 h a day. Thus, its operating period could be extended by 8-10 h/night to accommodate a larger vehicle fleet.

The fuelling station operated rather satisfactorily, and only a small number of repairs and modifications had to be carried out. These are briefly reported below.

Premature compressor shutdowns caused by a faulty oil level switch were prevented by recalibrating the switch and introducing an auxiliary lubricating oil reservoir. The master check valve on the compressor outlet was replaced, since it failed after 850 h of operation. In the third month of operation, compressor lubricating oil was detected in vehicle regulators. This was due to piston blowby which was checked by introducing an oil separator into the compressor outlet. The separator accumulates approximately 0.25 L of oil per week.

The flexible gas refuelling hoses on the seven risers (standards) had to be replaced three times since they developed leaks. It is not clear that a long-term solution has been found to this problem. The fill valve assembly at the end of each refuelling hose had to be replaced since the original ones developed leaks and proved to be relatively cumbersome to operate.

The automatic quick-fill cascade system had to be overhauled by replacing all o-rings and seals in the sequential valves. This was necessitated by

the erratic operation of the system which made proper cascading impossible. Also, a dome-loaded regulator was introduced into the cascade which resulted in improved operation with cascade storage at 24.8 MPa and temperature compensated slow-fill operation, viz., 20.7 MPa at 21°C.

3.2/ Vehicle Fleet Performance

Prior to the Consumers' Gas demonstration, the performance characteristics of CNG fleets in the Ontario environment were largely unknown. Consequently, there was a great need, especially among fleet operators, to find out about the fuel consumption, maintenance, driveability, safety and exhaust emissions of vehicles operated in Ontario. The Consumers' Gas demonstration was an attempt to quantify some of these vehicle characteristics by way of collecting operating data on a typical commercial light-duty vehicle fleet over a one-year period. Fuel consumption could be determined quantitatively by accumulating and processing the fuel acquisition and kilometrage records of the CNG demonstration fleet and a parallel gasoline baseline fleet. The driveability, maintenance and safety of these vehicles were assessed qualitatively by keeping detailed records of driver comment and work orders. In addition, the fuel consumption, exhaust emissions and performance of two of the CNG demonstration vehicles were measured in the MTC chassis dynamometer laboratory.

The results of this aspect of the demonstration program are discussed in some detail in the remainder of this section. It is expected that most of these results are sufficiently general to apply to a wide range of light-duty vehicle fleets.

3.2.1/ Fuel Consumption

The demonstration program was expected to produce comparative data in natural gas and gasoline consumption of two service van fleets operating under similar environmental conditions and on similar driving cycles.

This requirement was met by monitoring the fuel consumption and kilometrage of a 22-vehicle natural gas fleet and a 19-vehicle gasoline fleet over a one-year period. The two fleets operated from separate stations; however, both perform the same function in similar areas of Toronto.

The natural gas fleet was fuelled exclusively at the fleet depot. Almost always fuelling was carried out by an overnight slow-fill operation. The driver of each vehicle was expected to note the gas tank pressure and the ambient temperature just before and after the fuelling operation. These records were subsequently converted to a volumetric measurement of the natural gas dispensed at each fill-up by employing standard pressure-volume-temperature charts commonly used by the gas industry and by knowing the volume of the vehicle tanks and the composition of natural gas. This measurement technique is suitable for slow-fill operation where the temperature of the natural gas in the vehicle tank never diverges widely from ambient temperature.

This technique is compared with the mass flow technique in Reference 7, where they are reported to be in good agreement and better than 1% accurate. However, the application of the PVT relationships is more difficult in fast-fill operation or, more generally, in any non-equilibrium process.

Although the drivers of the natural gas fleet minimized the use of gasoline, there were instances when this could not be avoided. In some of the reported instances, the vehicle had run out of natural gas or it could not be started on natural gas on cold mornings. These occurrences may have contributed to an error in the quantification of vehicle fuel economy. The magnitude of this error is not expected to exceed 5%.

The gasoline fleet was fuelled in private gasoline stations; and individual vehicle fuel consumption was estimated from purchase bills. This method proved to be less satis actory as evidenced by the scatter in the data presented in this section.

In the analysis of the data, Consumers' Gas totalled both the natural gas and gasoline fleet records to estimate fuel consumption on a monthly basis. This allowed us to correlate fuel consumption with ambient temperature conditions. However, it should be noted that due to a time lag in the processing of fuel bills, monthly gasoline consumption data may be in error. This could, in fact, be one of the major contributors to the scatter in the gasoline data.

The demonstration data supplied by Consumers' Gas in their three interim reports [1,2,3] was independently analysed at MTC. In this analysis total fleet and individual vehicle fuel consumption data were treated separately. The use of total fleet data is adequate to produce an overall efficiency assessment. However, the accuracy of this assessment can only be judged by performing a statistical analysis on individual vehicle fuel consumption data.

The CNG and gasoline fleet fuel consumption and kilometrage for the demonstration period (October 1, 1981-September 30, 1982) are summarized in Table 1. These data indicate that average natural gas and gasoline consumption were 27.2 m^3/100 km and 31 L/100 km, respectively. These results imply that 88 m^3 of natural gas is equivalent to 100 L of gasoline. Furthermore, if we adopt typical lower heating values of 32.4 MJ/L for gasoline and 33.6 MJ/m^3 for natural gas one arrives at a nominal efficiency advantage of 9% for the natural gas fleet. However, as discussed below, the quality of the gasoline fleet data is inadequate to assign a high level of significance to this advantage.

A month-to-month comparison of the efficiency of the natural gas and gasoline fleets is provided in Table 2 and Figure 1. Here, energy consumption rather than fuel consumption is considered in order to provide a common basis for comparison. As shown, the data does not display a consistent efficiency difference between the two fleets. This appears to be mainly due to inconsistencies in the gasoline consumption data. However, the CNG fleet data indicates good correlation between energy consumption and average monthly ambient temperature. In order to illustrate this observation CNG fleet energy consumption is plotted in Figure 2 against monthly average ambient temperature. The data display good linear correlation with a correlation coefficient of 0.99 and a least-squares regression line given by:

Energy Consumption (MJ/100 km) = -14.3 x T(°C) + 999.5.

Comparison of fleet fuel consumption during the warmest and coldest three-month periods of the demonstration program reveals a substantial difference. During December to February, fuel consumption of the CNG and gasoline fleets were 31.5 m^3/100 km and 33.7 L/100 km, respectively.

Consumption fell to 22.1 m^3/100 km and 25.2 L/100 km, respectively during June to August. These represent 25-30% reductions in natural gas and gasoline consumption.

The individual vehicle fuel consumption data and associated statistics are summarized in Tables 3 and 4 for the CNG and gasoline fleets, respectively. The vehicle-to-vehicle variation in CNG consumption within a given month is reasonably small -- the 90% confidence intervals are at most 4 m^3/100 km wide. The month-to-month variation is well-correlated to average ambient temperature. Thus, the CNG fleet data presents a consistent picture of fuel consumption. The same cannot be said for the gasoline fleet data. The vehicle-to-vehicle variation, in this case, is much higher -- the 90% confidence intervals are as wide as 13 L/100 km. The month-to-month variation of gasoline consumption is also large and does not present a strong correlation with ambient temperature (Figure 1). Largely due to the scatter in the gasoline fleet data, the energy consumption difference between natural gas and gasoline fleets is not significant at a 0.90 confidence level. For further illustration of the month-to-month variation in individual vehicle CNG and gasoline consumption, two sets of representative data were plotted in Figures 3 and 4.

The fleet test results may be compared with chassis dynamometer data produced with two of the Consumers' Gas vehicles in the MTC laboratory. This work was done in the early stages of the demonstration program in order to assist Consumers' Gas with the assessment of their conversions. It is documented in a separate MTC publication [6]; however, for ease of reference, its main results are included in Tables 5, 6 and 7 of this report. The fuel consumption data therein indicate that as a result of the conversion, one of the vehicles tested enjoyed a substantial improvement in energy efficiency while the other suffered a major deterioration. This finding was acted upon by Consumers' Gas, who, with the assistance of the equipment supplier, improved the conversion. The fuel consumption of the more successful dual-fuel vehicle was found to be 15.29 m^3/100 km in city driving. This figure should be compared with the average fleet fuel consumption of 27.2 m^3/100 km. Some of the contributing factors to this large discrepancy may be identified as differences in driving cycle, and ambient conditions. Specifically, excessive idling and sustained

stop-and-go operation are expected to be largely responsible for the apparent inefficiency.

3.2.2/ Maintenance

One of the main objectives of this demonstration program was to assess the impact of dual-fuel operation in the Ontario environment on overall vehicle maintenance. By this process, Consumers' Gas intended to have an early chance to rectify any possible difficulties and to promote possible advantages.

Based on the European experience, natural gas was expected to provide maintenance benefits in extended engine and spark-plug life. Among these, the extension of the oil life was deemed to offer sufficient economic benefits to warrant investigation. Over the project duration, three sets of engine oil samples were subjected to spectrographic analysis. Their results indicated that the regular oil drain interval of 2000- 3000 km may be extended to 4500-5000 km in Ford vans. However, this was not feasible in GMC engines which appeared to suffer from excessive levels of silicon accumulation. At present, Consumers' Gas is monitoring the long term effects of the extended oil drain interval in the Ford engines. During the project, a number of equipment deficiencies and failures were reported [1-3]. Only two of these are deemed to be of general interest.

The first one involved the persistent failure of vehicle mounted check valves which were intended to prevent backflow of the natural gas from the vehicle tanks to the fuelling system. This problem was considered to be sufficiently serious to prevent drivers from connecting and disconnecting fill hoses. More commonly, the result was total loss of the on-board natural gas supply. Despite persistent experimentation with a number of alternative check-valves no satisfactory solution has been found.

The observation that check-value failure occurred mainly in winter and that similar difficulties were not reported in warmer countries suggests that hydrate formation within the valves may be the cause of this problem. If this hypothesis, proposed by Consumers' Gas, is verified then

installation of a desiccator or methanol injection unit at the compressor station would be a good solution to the problem.

It is worth noting that natural gas hydrates, which are essentially solutions of natural gas in ice, form under high pressure conditions, at temperatures much above the freezing point of water. For instance, natural gas hydrates may form at 10-20°C under 2000-3000 psi pressure [8].

The second reported deficiency with the CNG equipment involves its adverse effect on vehicle startability.

Under cold-weather conditions many Consumers' Gas vehicles cannot be started on natural gas. This necessitates the use of gasoline for vehicle starting. The extent of this problem was independently assessed by MTC on a Ford E-150 pick-up truck which is equipped with a CNG fuel systems conversion kit. A series of tests indicate that vehicle startability deteriorates strongly at subzero temperatures and unaided starting on natural gas becomes impossible at around -10°C. Further MTC testing with a number of starting aids is presently being conducted in an effort to identify the cause of this problem.

If liquid water is present in the natural gas fuelling system, hydrates will form which may explain the starting problem observed. Stiffening of regulator diaphragms under cold-weather conditions may affect fuel flow and thus also contribute to poor startability.

3.2.3/ Performance/Driveability

Consumers' Gas reported the performance of the converted vehicles running on natural gas to be noticeably inferior to that of the stock gasoline vehicles. In order to quantify this observation, they conducted a series of road tests which indicated that the 0-100 km/h acceleration time for the converted vehicles had increased by approximately 20%. In addition, they obtained dynamometer results indicating that the road-power of two representative vehicles had declined by 30% and 36% relative to their respective ratings.

At MTC, the performance of two representative Consumers' Gas vehicles, a GMC and a Ford van, were assessed on the chassis dynamometer by conducting 0-100 km/h acceleration tests and by measuring the power delivered at 80 km/h and wide-open-throttle operation. The results reveal an increase in acceleration time of 35% and 70% and a drop in power by 38% and 28%, respectively (Tables 5 and 6).

These performance results with gasoline and natural gas were obtained with converted, i.e., dual-fuel vehicles. Thus, they are indicative of the influence of the fuel only and not of the combined influence of the fuel and the conversion.

The dynamometer data generated by Consumers' Gas are in good agreement with the MTC results. However, there is a significant discrepancy between the acceleration period measured by Consumers' Gas on the road and those measured by MTC on the chassis dynamometer. Between these two, the Consumers' Gas results are more representative and in better agreement with the experience documented in the literature [9,10].

The performance loss as evidenced by the 20% increase in acceleration time may be reduced by optimizing the engine spark-timing. The Consumers' Gas vehicles which are expected to run both on natural gas and gasoline, operate with a compromise spark-timing schedule. The specific individual optimal timing schedules applicable to natural gas and gasoline may be implemented by the application of "dual-ignition curve" spark-timing devices.

The driveability of the Consumers' gas vehicles was assessed to be acceptable. Only a few complaints were reported by the drivers. One of the complaints involved the poor cold-starting characteristics described in the maintenance section of this report. A second complaint arose from a vehicle handling change caused by the mounting of the CNG cylinders. The unsymmetric distribution of weight in the vans results in a shift of the vehicle centre of gravity which is a specific installation result and cannot be classified as an intrinsic problem.

In the MTC evaluation of the Consumers' Gas vehicles, one of these was noted to display a "rough idle" symptom. An air-fuel ratio analysis

indicated that its carburation was set very lean. In fact, this was one of the contributors to its relatively high fuel efficiency. Subsequent MTC work has demonstrated that idle air-fuel ratio adjustment in natural gas engines is more critical than on gasoline engines. This is expected to be due to the narrower flammability range of natural gas/air mixtures.

3.2.4/ Exhaust Emissions

As part of the MTC chassis dynamometer evaluation of the Consumers' Gas fleet, the exhaust emissions of pollutants from two vans were assessed while operating on gasoline and natural gas. This was accomplished by measuring hydrocarbon, carbon monoxide and nitrogen oxides emission levels during the urban and highway chassis dynamometer driving schedules.

The data obtained in this work (Tables 5 and 6) lead to a number of important conclusions. The observation that the CO exhaust emissions of both vehicles were rather high, viz., 8.04 and 13.24 g/mile, while running on gasoline, indicates that both vehicles were running on relatively rich air-fuel mixtures and were relatively inefficient. In addition, the Ford van emitted a large amount of oxides of nitrogen. It would be difficult to explain this observation for a relatively rich air-fuel mixture unless the exhaust gas recirculation mechanism were malfunctioning.

On natural gas, the GMC vehicle produced extremely small amounts of CO implying rather lean operation with natural gas and an improvement in efficiency. With the Ford vehicle the CO emissions were even higher (45.28 g/mi) on natural gas than on gaaoline implying a further enrichment of the air-fuel mixture and a deterioration in fuel efficiency.

The above conclusions agree with those drawn from the fuel consumption measurements recorded in the same Tables 6 and 7. As noted before, the fuel consumption measurements indicate that the GMC vehicle operates more efficiently on natural gas than on gasoline while for the Ford vehicle the converse is true. The exhaust emission measurements offer a partial explanation to this observation, viz., the differences in the air-fuel ratio. It also indicates that the very impressive improvement in efficiency observed with the GMC van is partly due to its poor efficiency on

gasoline and partly due to its unusually lean natural gas carburation adjustment. Thus, this experience cannot be generalized. The exhaust emissions measurements also point to the inadequacy and variability involved in conversions made without good diagnostic equipment.

4/ CNG ECONOMICS

The market success of natural gas as a transportation fuel will largely depend on its cost competitiveness with gasoline. At present, the per unit energy price of natural gas is lower than that of gasoline. However, use of natural gas entails additional costs which are either not borne or are widely shared by gasoline users. These include the cost of retrofitting gasoline engine equipped vehicles to run on natural gas and the cost of building and running compressed natural gas fuel stations.

Recognizing these impediments to the adoption of natural gas, both the Federal and Provincial Governments have introduced subsidies and tax exemptions to vehicle and station operators. It is only because of these measures that a limited number of natural gas conversions have been made in Ontario and the rest of Canada.

The experience gained in the Consumers' Gas demonstration and a number of parallel MTC activities can be put to use to estimate the present economics of natural gas utilization. It is understood that such an analysis cannot be applicable to all potential users and that changes in the technology and costs may rapidly alter the overall economics. However, it is still useful to summarize the experience made to this point.

As part of their marketing efforts, Consumers' Gas have already published a report [11] on CNG utilization considering the economics of buying natural gas from a public fuelling station versus that of operating a private fuelling station. The analysis provided below parallels the Consumers' Gas approach, however, it incorporates assumptions which are expected to be more generally applicable.

Economics of CNG Purchased from Public Fuelling Stations

In this case, the economic position of the individual vehicle or fleet operator purchasing CNG from a public fuel station is considered. The main cost incurred by such an operator is the vehicle conversion cost, which is partially offset by a Federal Government grant of $600 per vehicle and, possibly, by an Ontario Government provincial sales tax rebate. This latter incentive applies to the purchase of a new vehicle which is equipped with a natural gas conversion system. The main benefits in-

curred by the operator is the difference in the unit energy costs of natural gas and gasoline.

The annual saving arriving from this cost difference have to be discounted to the present day in order to predict a fair payback period and the total savings possible over the lifetime of the equipment.

It is obvious, that some of the key parameters to be included are simply estimates and forecasts, which are specified below.

Conversion cost per vehicle	= $1 800
Federal grant	= $ 600
Net conversion cost	= $1 200 (case 1)
Provincial Sales tax rebate ($10 000 vehicle)	= $ 700
Minimum net conversion cost	= $ 500 (case 2)
Fuel cost difference per litre equivalent of gasoline	= $0.25
Discount rate	= 10%

The discounted payback period resulting from the above assumptions is presented in Figure 5. Here, the two cases of retrofit application, with a net conversion cost of $1200 and new vehicle application with a net conversion cost of $500 are displayed. For a typical per vehicle annual fuel consumption level of 2000 L the payback periods are 2.9 and 1 years, respectively. The total net saving incurred in the 10-year lifetime of the conversion equipment is expected to be $1872 and $2572, for the two cases considered here. At a 4000 L/vehicle annual fuel consumption level which is typical of fleet operations, the payback periods drop to 1.3 and 0.5 years, respectively.

In the above analysis, the tax implications of the conversion are omitted. This consideration, although irrelevant for most private vehicle owners, might have significant economic consequences for businesses and self-employed individuals. The maintenance cost implications of natural gas conversions are also neglected, since currently there is no clear indication of a net benefit or loss in this area. Operation on natural gas is expected to enhance engine longevity and to reduce some scheduled

maintenance costs; however, these benefits have to be offset against greater maintenance requirements for vehicle fuelling systems.

Economics of CNG Supply from Private Refuelling Station

In this case, the economic position of a fleet operator who owns and runs his own CNG refuelling station is considered. The main costs incurred by such an operator are his capital investments in the station and in the vehicle conversions.

The overall economics of this operation will depend on the size and rate of utilization of the fleet. Specifically, as the size and rate of utilization of the fleet increases, i.e., the CNG consumption increases, the economics of the operation improves.

It is evident that in the private refuelling station case there are a greater number of options and therefore a greater degree of variability in the resulting economics. In what follows, a typical fleet operation with 50 CNG vehicles will be considered. As before, the total CNG consumption, expressed as litre equivalents to gasoline, will be considered a variable.

Vehicle fleet size	= 50
Conversion costs ($1800 x 50)	= $ 90 000
Federal grants ($ 600 x 50)	= $ 30 000
Net vehicle conversion costs	= $ 60 000 (case 1)
Provincial tax rebate: $700 x 50	= $ 35 000
Minimum net vehicle conversion costs	= $ 25 000 (case 2)
Refuelling station cost	= $180 000
Fuel cost difference per litre equivalent of gasoline	= $0.275
Discount rate	= 10%

The discounted payback period resulting from the above assumption is presented in Figure 6 for the two net vehicle conversion cost scenarios, i.e., $60 000 and $25 000. For a 4000 L/vehicle annual fuel consumption level the discounted payback periods are predicted to be 4.2 and 3.2 years for the two vehicle conversion cost scenarios. The payback periods improve significantly as the fleet fuel consumption increases. For

instance, at 6000 L/vehicle consumption level, which is typical of taxi fleets or heavier vehicle fleets, the payback periods become 2.64 and 2 years, respectively.

The above analysis suggests that from the end user's point of view, the preferred way of CNG acquisition is that of purchase from a public station. The main reason for this outcome is the relatively small difference (0.25¢/L) in the cost of natural gas obtained from the public station versus from a private station. It is not entirely obvious, that this cost differential will prevail. At present, demand on CNG is relatively low and the few Canadian public fuelling stations are operating below their capacity. It is conceivable that higher demand on CNG would force the CNG prices up and the cost differential would become larger.

The acquisition of a private fuelling station becomes attractive when the utilization rate of the station exceeds 50%.

This can be accomplished by selecting the most suitable fleets, also with providing a sufficient number of slow-fill lines and adequate fast-fill capacity. Although strictly economic factors may suggest the use of a public station, the present scarcity of public stations dictates the need to acquire private fuelling stations.

By above measures, the Consumers' Gas application involving 22 vans only could not be considered an economically attractive project. However, at present the fleet size has been expanded to approximately 40 vehicles and this will undoubtedly contribute to the economic success of the project.

5/ CONCLUSIONS

The technology and economics of natural gas as a vehicle fuel in Ontario were successfully demonstrated by the Consumers' Gas Co. Ltd. in a program jointly funded by industry and government. As part of the program a slow-fill/fast-fill CNG fuelling station with a nominal capacity of 110 m^3/h (65 scfm) was built and 22 service vans were converted to operate on a CNG/gasoline dual-fuel mode. Consumers' Gas carefully monitored and reported the performance of the fuelling station and the vehicle fleet during a one-year demonstration period.

The results of these reports were analysed by MTC in order to derive general information that can be disseminated to potential CNG fuel users. The main conclusions of this study are the following:

1/ In a service fleet operation involving urban driving conditions and prolonged idling periods, fuelling of spark-ignition engines with either natural gas or gasoline results in comparable energy utilization efficiencies. Consumers' Gas predicts a 9% efficiency advantage for CNG; however, statistical analysis of the fleet data indicates a rather low confidence level for this prediction. Thus, until a more reliable data base is established the road fuel consumption equivalence of the two fuels has to be based on their energy contents; i.e., 1 L of gasoline can be typically substituted by 0.96 m^3 of natural gas.

2/ Large variations in relative fuel efficiency with natural gas and gasoline may arise from differences in the pre-conversion state of the vehicles and the conversion process. This observation was made during the MTC chassis dynamometer evaluation of two Consumers' Gas dual-fuel vehicles. Reduction of such variations requires that prior to conversion each vehicle is set to manufacturers' specifications and that during conversion the ignition and carburation systems of each vehicle are adjusted to minimize CNG consumption while retaining adequate performance.

3/ The average CNG consumption of the demonstration fleet was 27.2 $m^3/100$ km. The month-to-month variation of the fleet fuel con-

sumption was relatively large, with the 90% confidence interval for the average monthly fleet fuel consumption being 2.6 m^3/100 km wide. However, this variation correlates very well with ambient temperature and constitutes a systematic variation. For instance, CNG consumption in the coldest three months of 1981/82 was found to be approximately 30% higher than that in the warmest three months. The vehicle-to-vehicle variation in CNG consumption which constitutes a random variation is less pronounced, viz., the 90% confidence interval for the average annual vehicle fuel consumption is 0.8 m^3/100 km wide. Thus, the Consumers' Gas demonstration has succeeded in producing consistent CNG consumption data.

4/ The use of natural gas appears to provide the potential of doubling engine oil life. This preliminary finding is going to be substantiated by Consumers' Gas as part of their on-going development program.

5/ A number of deficiencies were discovered in the CNG demonstration vehicles. These included frequent failure of the vehicle mounted fuel check-values, poor cold-weather startability, rough engine idling and 20% reduction of acceleration performance. These deficiencies can be eliminated by research and development aimed at improving conversion equipment and designing optimized natural gas engines.

6/ The fuelling station dispensed 68 000 m^3 of natural gas during the demonstration period. In this process, 11 094 kWh of electricity were consumed. Thus, the average compression energy consumption amounted to approximately 16 kWh/100 m^3.

7/ The operation of the fuelling station ran smoothly. However, a number of failures related to seals, regulators, valves and switches were encountered which caused temporary shutdown of the system. Consumers' Gas will continue to monitor the performance of the fuelling station components in an effort to overcome difficulties that relate specifically to the use of natural gas.

8/ Measurement of the exhaust emission levels of two of the fleet vehicles at MTC indicate that the CNG conversion equipment and procedures

may strongly alter the level of pollutant emissions. Contrary to common belief, a poor CNG conversion may result in more pollution.

9/ The cost-benefit data accumulated during the demonstration indicate that under the present pricing structure and with the existing government grants and tax incentives, use of natural gas as a a vehicle fuel is very economical in Ontario. Operators who choose to purchase natural gas from public retail stations can expect to pay for the conversion costs in 0.5-3 years depending on whether factory-conversion or a retrofit is involved and depending on the annual CNG consumption. On the other hand, for those who choose to operate their own fuelling station and a CNG vehicle fleet the payback period for the station and the conversion of the vehicles is expected to be 2-4.2 years provided that at least 50% of the station capacity is utilized on an annual basis.

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Table 1/ Total Fleet Fuel Consumption

Period	CNG FLEET		GASOLINE FLEET	
	Consumption (m^3)	Kilometrage (km)	Consumption (L)	Kilometrage (km)
Oct./Nov. 81	11 694	41 166	8 847	26 920
December 81	5 269	17 846	6 400	21 850
January 82	5 901	17 830	6 762	21 975
February 82	6 102	19 128	7 075	16 318
March 82	5 918	20 420	6 742	20 077
April/May 82	9 401	36 590	9 059	29 859
June 82	3 794	15 998	3 507	15 868
July 82	2 756	12 863	4 936	16 558
August 82	2 434	10 851	2 500	10 513
September 82	3 854	17 224	5 234	16 885
Total	57 123	209 916	61 062	196 823

Table 2/ Average Energy Efficiency of Natural Gas and Gasoline Fleets

Period		Average Temperature (°C)	CNG Fleet Energy Consumption (MJ/100 km)	Gasoline Fleet Energy Consumption (MJ/100 km)
Oct./Nov.	81	5.8	960	1072
December	81	-2.0	1024	972
January	82	-9.0	1142	946
February	82	-6.2	1105	1442
March	82	-0.9	967	1092
April/May	82	10.0	828	1001
June	82	15.9	788	716
July	82	20.9	720	966
August	82	17.3	754	770
September	82	14.8	752	437
Average		6.7	904	941
Range		30	422	1005
St. Dev.		10.7	155	265
90% CI		2 - 12	836-972	825-1057

Table 3/ Fuel Consumption of CNG Vehicles

Vehicle No.	Fuel Consumption (m^3/100 km)													
	Oct./Nov. (1981)	Dec.	Jan.	Feb.	Mar.	Apr./May (1982)	June	July	Aug.	Sept.	Avg.	Range	St. Dev.	90% CI
1	26.3	27.5	33.1	34.4	30.7	28.7	23.9	-	-	22.4	28.4	12	4.2	26-31
2	34.4	25.2	39.0	32.6	31.1	24.0	22.0	24.5	24.0	23.8	28.1	17	5.8	26-31
3	25.6	41.9	42.7	37.6	31.2	28.5	29.0	25.5	30.0	27.0	31.9	17	6.5	29-35
4	32.4	31.9	24.7	33.4	29.9	27.7	24.9	21.4	20.4	22.0	26.9	13	4.9	25-29
5	34.4	39.3	40.5	40.8	28.5	28.4	26.4	20.1	-	-	32.3	21	7.6	28-36
6	31.2	29.2	33.3	30.6	28.8	24.0	21.3	19.4	19.8	22.2	26.0	14	5.2	24-28
7	29.0	32.0	24.9	36.5	27.1	23.7	22.5	21.2	20.0	21.5	25.8	16	5.3	24-28
8	27.0	29.5	30.2	29.3	27.1	24.5	23.2	20.6	20.8	20.0	25.2	10	3.9	23-27
9	26.3	28.6	32.9	31.0	27.5	22.8	20.3	17.9	18.4	18.7	24.4	15	5.6	22-27
10	23.4	26.3	32.7	29.8	30.1	-	-	-	-	-	28.5	9	3.6	25-32
11	31.1	25.7	31.4	33.2	26.3	23.9	24.0	21.3	24.2	21.7	26.3	12	4.2	24-28
12	30.4	26.0	31.8	37.1	21.0	25.3	21.4	24.3	21.0	25.1	26.3	16	5.3	24-29
13	27.2	31.2	38.2	30.8	27.1	24.5	22.6	21.2	22.4	23.0	26.8	17	5.3	24-29
14	27.5	29.2	32.3	36.7	31.0	24.5	21.6	20.3	20.5	21.8	26.5	16	5.7	24-29
15	23.0	32.0	31.1	24.9	26.9	21.4	24.1	20.0	25.0	22.6	25.1	12	3.9	23-27
16	34.8	37.6	29.5	33.9	28.9	22.0	17.2	21.6	22.1	21.6	26.9	20	6.9	24-30
17	24.8	29.2	38.8	34.7	30.2	23.2	23.5	22.7	24.9	19.8	27.2	19	6.0	25-30
18	27.2	24.1	35.7	30.4	34.7	27.5	27.6	20.7	24.1	27.7	28.0	15	4.6	26-30
19	27.7	30.3	37.1	33.1	29.1	22.2	20.6	20.1	19.5	21.9	26.2	18	6.2	23-29
20	28.4	29.5	31.7	25.4	25.9	22.6	23.5	21.3	24.1	23.5	25.6	10	3.3	24-27
21	22.4	27.2	32.7	28.0	21.8	21.2	24.2	21.4	21.0	22.5	24.2	12	3.9	23-26
22	27.1	33.3	38.3	35.7	33.5	24.8	25.6	25.4	26.1	23.9	29.4	14	5.3	27-32
Average	28.4	30.3	33.8	32.7	28.6	24.5	23.3	21.5	21.5	22.6				
Range	12	18	18	16	14	8	12	8	12	9				
St. Dev.	3.8	4.5	4.6	4.0	3.2	2.4	2.6	2.0	2.0	2.2				
90% CI	27-30	29-32	32-36	31-34	27-30	24-25	22-24	21-22	21-22	22-23				

Table 4/ Fuel Consumption of Gasoline Vehicles

Vehicle No.	Fuel Consumption (L/100 km)													
	Oct./Nov.	Dec.	Jan.	Feb.	Mar.	Apr./May	June	July	Aug.	Sept.	Avg.	Range	St. Dev.	90% CI
1	28.5	30.2	19.3	30.1	32.4	27.8	18.0	27.1	25.4	12.8	25.2	19	6.3	22-28
2	44.0	-	13.8	36.5	18.0	-	7.8	20.1	23.1	-	23.3	36	12.7	16-30
3	34.3	26.1	35.9	43.5	19.2	27.5	17.7	20.6	32.2*	13.0	27.0	30	9.5	23-31
4	33.1	39.7	28.6	65.1	36.8	-	-	24.3	34.3*	13.0	34.4	52	15.0	28-41
5	44.9	21.4	45.1	20.5	43.2	38.0	61.9	54.4	30.6*	7.7	36.8	54	16.7	30-44
6	27.9	37.5	25.3	47.9	34.1	37.0	13.3	25.3	29.0*	7.4	28.5	40	11.8	23-34
7	28.5	45.3	46.2	46.8	57.9	31.5	28.4	29.2	17.6	-	36.8	40	12.7	31-43
8	-	23.2	22.7	51.4	26.9	25.9	20.2	15.9*	31.1	21.5	26.5	35	10.3	22-31
9	32.2	20.2	24.8	34.2	32.1	16.1	38.5	86.6	19.7*	18.5	P2.3	70	20.6	23-41
10	37.8	20.6	25.1	52.4	22.2	-	-	27.5*	14.5	12.9	26.6	39	13.0	20-34
11	34.3	35.0	46.6	12.5	46.5	28.2	24.4	31.5	43.1	7.6	31.0	39	13.3	25-37
12	35.7	19.1	26.3	50.8	39.4	-	9.4	21.1	18.5	-	27.5	41	13.5	20-35
13	33.8	25.4	30.8	33.8	36.5	24.6	32.2	26.5	21.8	9.5	27.5	26	7.9	24-31
14	27.9	25.4	24.1	69.5	31.6	18.9	17.8	46.4	25.8	11.2	29.9	58	16.8	23-37
15	34.5	35.9	-	68.6	24.5	52.6	26.8	72.7	16.3	-	41.5	57	20.9	31-52
16	23.8	32.9	32.9	44.5	34.8	29.8	31.3	13.8	28.1	17.9	29.0	30	8.8	25-33
17	27.1	25.8	19.3	33.1	33.5	34.6	10.3	20.7	32.6	11.3	24.8	23	9.1	21-29
18	-	-	-	-	-	-	8.4	46.3	36.2	28.4	29.8	38	16.0	16-44
19	34.2	46.1	29.1	59.5	37.5	40.6	45.5	61.4	30.4	17.4	40.2	44	13.6	34-46
Average	33.1	30.0	29.2	44.5	33.7	30.9	25.2	35.3	26.9	14.0				
Range	21	27	27	57	40	36	54	73	27	21				
St. Dev.	5.7	8.7	9.6	15.8	9.8	9.3	14.5	20.4	7.6	5.8				
90% CI	31-36	26-34	25-33	38-50	30-38	27-35	19-32	21-33	25-29	12-16				

* new vehicles

Table 5/ MTC Dynamometer Test Results

Fuel Consumption, Exhaust Emissions and Performance with Gasoline

		GMC VANDURA 25	FORD E-150
FUEL CONSUMPTION			
Urban Driving			
Cold-Transient	(L/100 km)	17.94	18.33
Stabilized	(L/100 km)	17.45	16.99
Hot-Transient	(L/100 km)	15.43	16.55
Combined	(L/100 km)	17.06	17.04
Highway Driving	(L/100 km)	12.50	13.13
Idling (Park)	(L/h)	2.19	2.44
Idling (Drive)	(L/h)	2.11	2.39
48.3 km/h Cruise	(L/100 km)	9.64	9.49
96.6 km/h Cruise	(L/100 km)	14.66	14.68
HYDROCARBON EMISSIONS			
Urban Driving			
Cold-Transient	(g/mi)	2.71	1.90
Stabilized	(g/mi)	0.868	1.58
Hot-Transient	(g/mi)	1.020	1.61
Combined	(g/mi)	1.29	1.65
Highway Driving	(g/mi)	0.302	0.72
CO EMISSIONS			
Urban Driving			
Cold-Transient	(g/mi)	17.81	34.25
Stabilized	(g/mi)	4.53	5.81
Hot-Transient	(g/mi)	7.34	11.44
Combined	(g/mi)	8.04	13.24
Highway Driving	(g/mi)	3.52	3.81

Table 5/ MTC Dynamometer Test Results (Cont'd)

NO_x EMISSIONS		GMC VANDURA 25	FORD E-150
Urban Driving			
Cold-Transient	(g/mi)	2.57	6.83
Stabilized	(g/mi)	1.35	4.19
Hot-Transient	(g/mi)	2.04	7.21
Combined	(g/mi)	1.79	5.57
Highway Driving	(g/mi)	1.61	7.68
PERFORMANCE			
0 to 96.6 km/h Acceleration Time			
In Drive (s)		14.0	17.6
In Second (s)		14.4	20.0
Power delivered at 96.6 km/h and WOT operation			
In Drive (kW)		75.0	64.0
In Second (kW)		75.0	60.3

Table 6/ MTC Dynamometer Test Results

Fuel Consumption, Exhaust Emissions and Performance with Compressed Natural Gas

		GMC VANDURA	FORD E-150
FUEL CONSUMPTION			
Urban Driving			
Cold-Transient	(m^3/100 km)	15.20	19.07
Stabilized	(m^3/100 km)	15.79	17.19
Hot-Transient	(m^3/100 km)	14.49	17.41
Combined	(m^3/100 km)	15.29	17.66
Highway Driving	(m^3/100 km)	11.76	14.49
Idling (Park)	(m^3/h)	2.30	2.33
Idling (Drive)	(m^3/h)	2.19	2.22
48.3 km/h Cruise	(m^3/100 km)	8.46	10.30
96.6 km/h Cruise	(m^3/100 km)	12.71	16.18
HYDROCARBON EMISSIONS			
Urban Driving			
Cold-Transient	(g/mi)	1.83	2.26
Stabilized	(g/mi)	1.36	1.91
Hot-Transient	(g/mi)	1.55	1.86
Combined	(g/mi)	1.51	1.97
Highway Driving	(g/mi)	0.77	1.67

Table 6/ MTC Dynamometer Test Results (Cont'd)

CO EMISSIONS		GMC VANDURA	FORD E-150
Urban Driving			
Cold-Transient	(g/mi)	0.58	68.70
Stabilized	(g/mi)	0.03	32.17
Hot-Transient	(g/mi)	0.03	52.64
Combined	(g/mi)	0.16	45.28
Highway Driving	(g/mi)	0.03	46.21
NO_x EMISSIONS			
Urban Driving			
Cold-Transient	(g/mi)	3.02	2.42
Stabilized	(g/mi)	0.99	2.44
Hot-Transient	(g/mi)	1.85	3.01
Combined	(g/mi)	1.64	2.59
Highway Driving	(g/mi)	1.48	2.98
PERFORMANCE			
0 to 96.6 km/h Acceleration Time			
In Drive (s)		24.1	23.2
In Second (s)		23.8	27.3
Power delivered at 96.6 km/h and WOT operation			
In Drive (kW)		47.7	44.4
In Second (kW)		45.6	44.4

Table 7/ Comparison of MTC Dynamometer Test Results

Energy Consumption with Gasoline and Natural Gas
(Comparison of Energy Utilization Efficiencies)

	GASOLINE	CNG	CNG ADVANTAGE
GMC VANDURA 25			
Urban Driving (MJ/100 km)	553	515	7%
Highway Driving (MJ/100 km)	405	396	2%
Idling (in Drive) (MJ/h)	68	74	-9%
Cruise (48.3 km/h) (MJ/100 km)	313	285	9%
Cruise (96.6 km/h) (MJ/100 km)	475	428	10%
FORD E-150			
Urban Driving (MJ/100 km)	552	594	-8%
Highway Driving (MJ/100 km)	426	486	-14%
Idling (in Drive) (MJ/h)	77	75	-3%
Cruise (48.3 km/h) (MJ/100 km)	308	347	-13%
Cruise (96.6 km/h) (MJ/100 km)	476	544	-14%

*Positive numbers indicate an energy utilization efficiency advantage for the CNG system.

Table 8/ Vehicle Specification
(MTC Dynamometer Tests)

Type	Van	Van
Make	GMC	Ford
Model	Vandura 25	E-150
Model Year	1980	1980
Licence No.	AE8-857	AF6-523
Kilometrage	38789 to 40123	25239 to 26435
Gross Vehicle Weight	3000 kg	2815 kg
Engine Type	Gasoline; L-6	Gasoline; L-6
Engine size	4.1 L	4.9 L
Transmission Type	A-3	A-3
Carburettor Type	2-BBL	2-BBL
Oxidation Catalyst	Yes	Yes
Air Injection	No	No
Exhaust Gas Recirc.	Yes	Yes
Evaporation Canister	Yes	Yes
Positive Crankcase Vent.	Yes	Yes

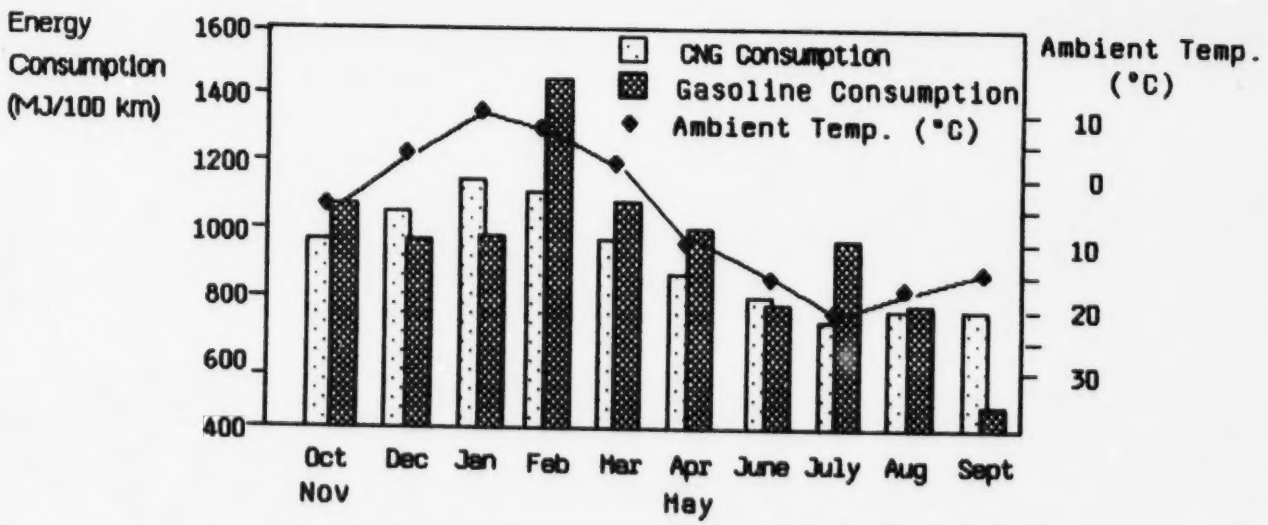

Figure 1/ Energy Consumption with Natural Gas and Gasoline

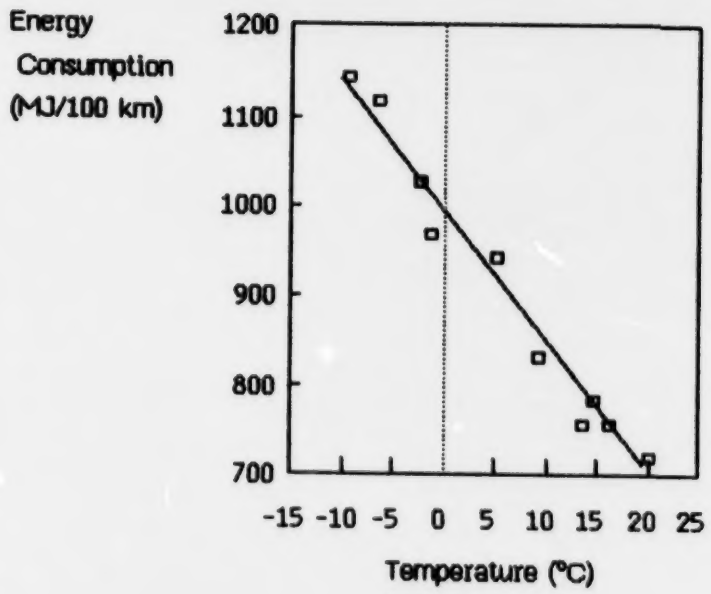

Figure 2/ Relation of Energy Consumption to Ambient Temperature

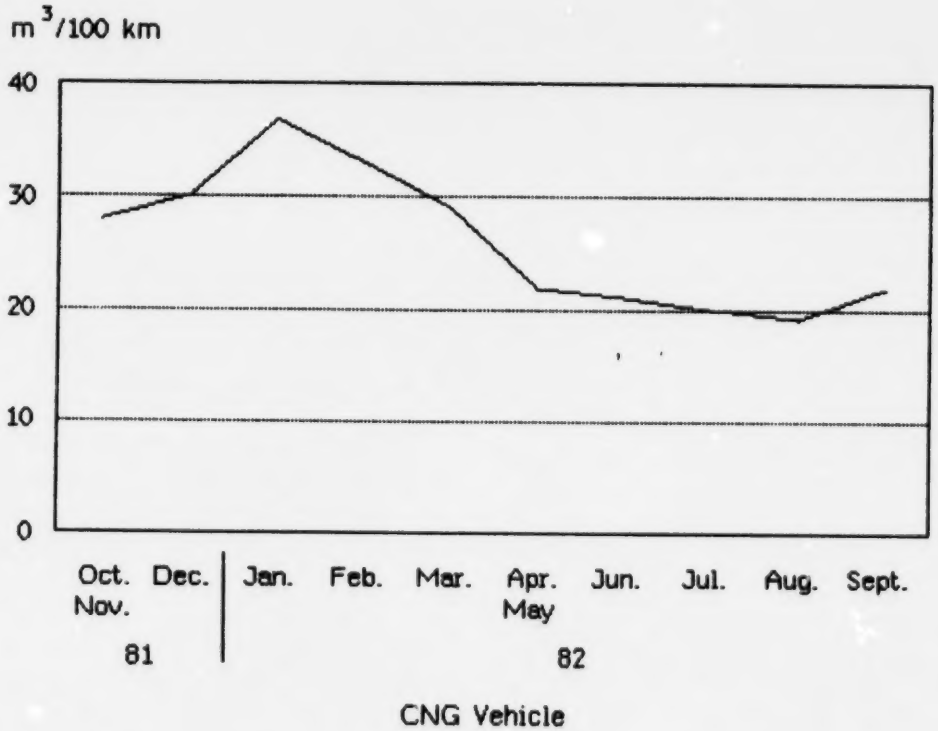

Figure 3/ Month-to-Month Fuel Consumption Variation
of a Typical CNG Demonstration Fleet Vehicle

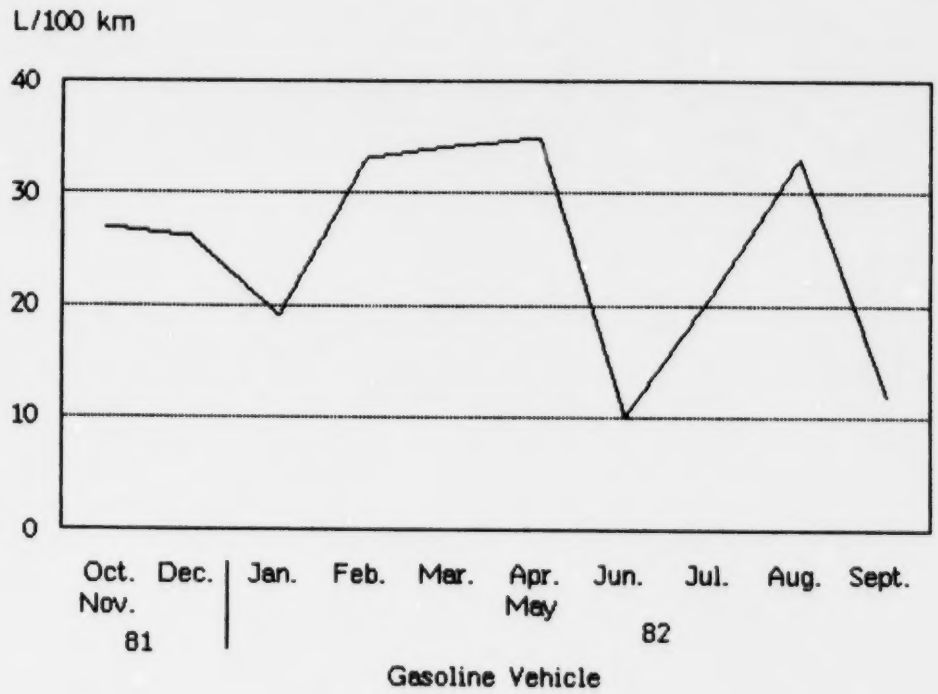

Figure 4/ Month-to-Month Fuel Consumption Variation of a Typical Gasoline Baseline Fleet Vehicle

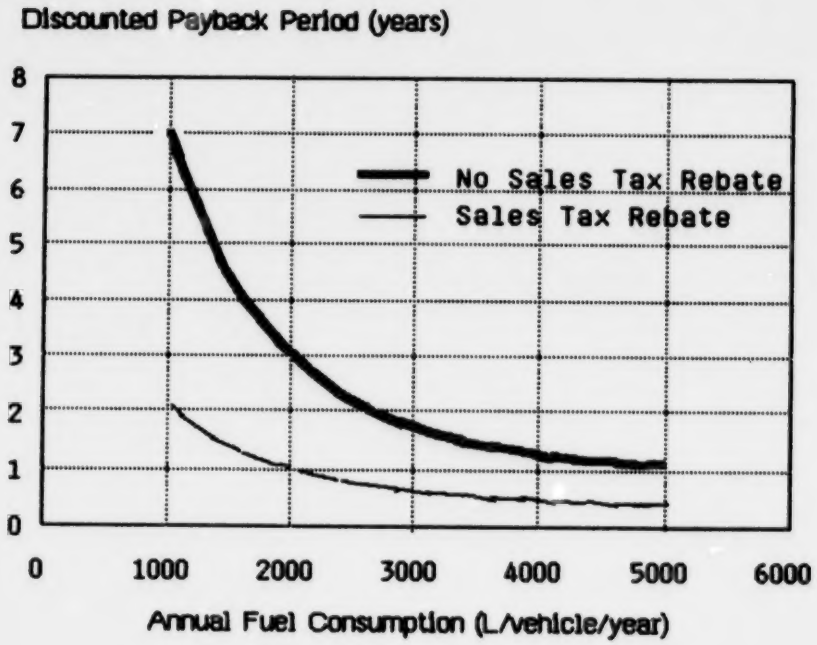

Figure 5/ Economics of CNG Purchase from Public Fuelling Station

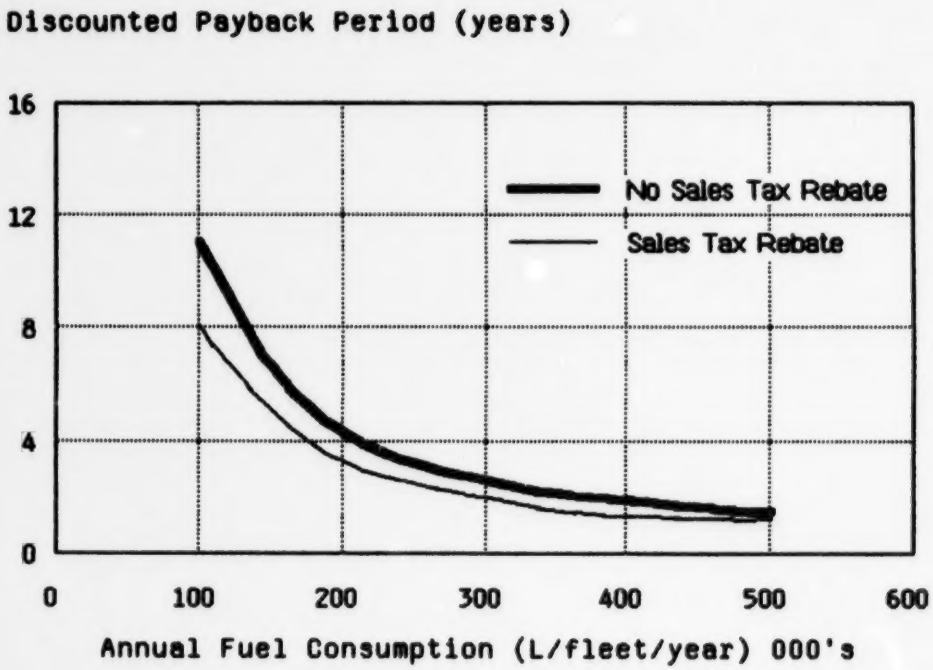

Figure 6/ Economics of CNG Supply from Private Fueling Station